PLAN TO CONDUCT EMISSIONS TESTING FOR RECIPROCATING INTERNAL COMBUSTION ENGINES

presented to:

Coordinating Committee
Industrial Combustion Coordinated Rulemaking

presented by:

Reciprocating Internal Combustion Engine Work Group
Industrial Combustion Coordinated Rulemaking

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1.0 INTRODUCTION

The Reciprocating Internal Combustion Engine (RICE) Work Group has determined that additional hazardous air pollutant (HAP) emissions data are necessary to support the regulatory development process, as described in the "Industrial Combustion Coordinated Rulemaking (ICCR) Organizational Structure and Process" document, dated June 1997. Supporting information is provided in **Appendix A** regarding the Work Group's determination that more emissions data are necessary to support the ICCR rule development for RICE.

In order to obtain additional emissions data (both air toxics and criteria pollutants), the Work Group is recommending this plan for emissions testing of stationary RICE. The RICE Work Group has developed this test plan with the knowledge that resources under ICCR are extremely limited. Therefore, the Work Group has developed this test plan as one that is achievable given the budget constraints within the ICCR process. The Test Plan does not address all the questions that must be answered regarding emissions from RICE and the effectiveness of potential maximum achievable control technology (MACT). However, the results of this test plan will provide additional emissions data and will address key data gaps that have been identified in the EPA ICCR Emissions Database for RICE.

1.1 Components of the Test Plan

The test plan has five components:

Engines, Fuels, and Emission Controls to be Tested
Matrix of Operating Conditions to be Tested
Pollutants to be Measured During Testing
Test Methods to Quantify Emissions
Prioritization

Each of these components is discussed in the sections that follow. A summary table for each emission test proposed is provided in the final section of this test plan.

1.2 Emissions Testing Goals Identified by RICE Work Group

The RICE Work Group has identified the following possible goals for emissions testing under ICCR:

1. acquire additional emissions data that can assist the Work Group in determining the effectiveness of after-treatment control devices to reduce formaldehyde and other HAPs;
2. acquire additional emissions data that can assist the Work Group in determining the effectiveness of combustion modifications to reduce formaldehyde and other HAPs;
3. acquire additional emissions data that can assist the Work Group in determining typical emissions for engines throughout the operating range.

The Work Group has designed the emissions test plan around Goal #1, for the following reasons:

- Emissions data to demonstrate the effectiveness of possible MACT control devices for existing RICE is a data gap in the ICCR Emissions Database for RICE. (see **Appendix A**)
- Understanding of the effects of combustion modifications on HAPs is in its infancy, and would require a very extensive research program to identify potential control techniques, along with confirming testing.
- EPA has endorsed the use of ICCR emissions testing dollars to achieve this goal.

In addition, the Work Group has further focused the plan to address the effectiveness of after-treatment control devices on formaldehyde emissions, primarily, and on other HAPs, secondarily. The Work Group will gather emissions data for all HAPs included on the target list of pollutants. However, the control devices to be tested were selected principally for their potential to reduce formaldehyde emissions. The Work Group has added this focus to the test plan for the following reasons:

- Formaldehyde is a product of incomplete combustion and generally is the HAP emitted in the greatest quantities from RICE.
- The Work Group was able to identify possible maximum achievable control technology (MACT) for formaldehyde based on the results of emissions testing conducted by industry. There is less understanding of possible MACT for other HAPs.

The test plan also will support Goal #3 in part, since pre-controlled emissions throughout a 16-point test matrix of operating conditions will be recorded during the testing program.

2.0 ENGINES, FUELS, AND EMISSION CONTROLS TO BE TESTED

2.1 Engines

The RICE Work Group recommends that a minimum of four engines be tested under ICCR. Each of the engines selected represents a possible subcategory of engines (see **Table 1**).

Table 1. Engines to be Tested

Engine to be Tested	Possible Engine Subcategory
Clark TLA Turbocharged	2-stroke, gaseous fuel
Caterpillar 3500 Series Turbocharged	liquid-fuel
Waukesha 7042 GL Turbocharged	4-stroke, lean-burn, gaseous fuel
Ingersoll Rand KVG Naturally Aspirated	4-stroke, rich-burn, gaseous fuel

Background information on engine configurations is provided in **Appendix B**.

2.2 Fuels

Diesel fuel has been selected as the liquid fuel to be tested. The Work Group selected diesel fuel because most stationary RICE that use liquid fuels use diesel.

Natural gas has been selected as the gaseous fuel to be tested. The Work Group selected natural gas because most stationary RICE that use gaseous fuels use natural gas.

2.3 Emission Controls

The Work Group recommends that the engines be tested with emissions control devices that have been identified as possible maximum achievable control technology (MACT). To date, the Work Group has identified oxidation catalysts as possible MACT for lean-burn engines. For rich-burn engines, the Work Group has identified non-selective catalytic reduction (NSCR) as possible MACT.

The control devices to be tested are presented in **Table 2**. The Work Group recommends that the Clark, Waukesha, and Caterpillar be tested with oxidation catalysts. The Work Group recommends that the Ingersoll Rand be tested with an NSCR catalyst.

Table 2. Control Devices to be Tested

Engines	Control Device
Clark TLA Turbocharged	oxidation catalyst
Caterpillar 3500 Series Turbocharged	oxidation catalyst
Waukesha 7042 GL Turbocharged	oxidation catalyst
Ingersoll Rand KVG Naturally Aspirated	non-selective catalytic reduction (NSCR)

Since catalyst design, formulation, and age can affect catalyst performance, the RICE Work Group will review each of these factors when selecting sites for testing.

3.0 MATRIX OF OPERATING CONDITIONS TO BE TESTED

The Work Group recommends that the engines be tested throughout the entire operating envelope. The Work Group has developed a 16-point test matrix of operating conditions to be tested (see **Table 3**). The test matrix includes varied speed, torque, air-to-fuel ratio, air manifold temperature, jacket water temperature, timing, and combustion balance as applicable to the specific engine's operating envelope. The tests are organized as follows:

- Four corners of the torque / speed envelope (runs 1-4)
- Air-to-fuel ratio sensitivity (runs 1, 5-6)
- High speed and low load (run 7)
- Low speed and high load (run 8)
- Air manifold temperature sensitivity (runs 1, 9-10)
- Jacket water temperature sensitivity (run s1, 11-12)
- Injection or spark timing sensitivity (runs 13-14)
- Engine balance sensitivity (runs 1, 15-16)
  - Same as run 1, but at limit of acceptable imbalance.

An abbreviated matrix will apply to the engines using diesel fuels due to a reduced ability to vary parameters. Specific settings for the four engines selected are presented in the summary tables in the final section of this test plan. It is estimated that the test matrix will require approximately three days of emissions testing for each engine.

The Work Group recommends that runs 1-14 be conducted with engine balance within the OEM (original equipment manufacturer) specification of good balance. An engine may be in stable operation and not conform to the OEM's balance specification. Engine balance is commonly defined in terms of the difference in peak combustion pressure or exhaust temperature between the highest value and lowest value cylinders of the engine. An engine with acceptable balance has the maximum difference(s) within a set OEM specification. To determine unbalance requires the proper instrumentation to measure these pressures and/or temperatures on the individual cylinders. To unbalance an engine (runs 15-16) requires an engine with the provision to adjust individual cylinder compression or ignition timing.

The Work Group recommends that an engine "expert" be on-site during all testing to ensure that the engine is properly balanced and is being tested in a well-maintained condition. More information on the engine set-up, carrying out the test runs, and data acquisition is provided in **Appendix C**.

Table 3. Matrix of Operating Conditions to be Tested

Run	Speed	Torque	Air-to-Fuel Ratio	Timing	Air Manifold Temperature	Jacket Water Temperature
1	H	H	N	S	S	S
2	H	L	N	S	S	S
3	L	L	N	S	S	S
4	L	H	N	S	S	S
5	H	H	L	S	S	S
6	H	H	H	S	S	S
7	H	L	H	S	S	S
8	L	H	L	S	S	S
9	H	H	N	S	L	S
10	H	H	N	S	H	S
11	H	H	N	S	S	L
12	H	H	N	S	S	H
13	H	H	N	L	S	S
14	H	H	N	H	S	S
15	H[1]	H[1]	N[1]	S[1]	S[1]	S[1]
16	H[1]	H[1]	N[1]	S[1]	S[1]	S[1]
*Notes: H = high-end setting L = low-end setting N = Nominal setting required to satisfy emissions S = set point	H and L to be determined based on operating range and control flexibility.	H, L to be determined based on operating range and control flexibility.	H, L to be determined based on operating range and control flexibility.	H, L to be determined based on operating range and control flexibility.		

[1] Same as Run #1 except with engine at limit of acceptable imbalance.

4.0 POLLUTANTS TO BE MEASURED DURING TESTING

The Work Group recommends that emissions data for both hazardous air pollutants (HAPs) and criteria pollutants be collected before and after emission control devices using two sample-line systems (inlet and outlet). More information on collection of the pollutant information is provided in **Appendix C**.

The HAPs and criteria pollutants to be measured during testing were determined based on the Work Group's list of principal pollutants that are reasonably anticipated to be emitted from the RICE and input on the pollutant lists from Coordinating Committee members and other participants in ICCR. The comments received and the Work Group's response to the comments are provided in **Appendix D**.

Emissions data for the following criteria pollutants will be collected:

- carbon monoxide (CO)
- nitrogen oxides (NOx)
- total hydrocarbons (THC)
- particulate matter (PM) (diesel only)

Seven HAP pollutants are included in the test plan for all engines, regardless of fuel:

- BTEX (benzene, toluene, ethylbenzene, and xylene) and
- three aldehydes (formaldehyde, acetaldehyde, and acrolein).

Naphthalene, 1-3, butadiene, and PAHs are included for natural gas and diesel fuel. In addition, n-Hexane and metals are included for diesel fuel. Chlorinated compounds that were originally included on the pollutant list for natural gas have been removed based on further review of the emissions test data in the ICCR Emissions Database and industry data related to the absence of chlorine in natural gas fuel. More information on the basis for removing the chlorinated compounds is provided in **Appendix D**. A list of pollutants for each proposed test is provided in the final section of this test plan. Diluent gas (oxygen and carbon dioxide) measurements also will be made.

5.0 TEST METHODS TO QUANTIFY EMISSIONS DURING TESTING

The Work Group recommends the use of emissions test methods that will provide direct measurement and reporting of pollutant concentrations on-site. This approach to the test methods has been selected since it will be necessary to have on-site data to fully evaluate and conduct the matrix of engine operating conditions.

The Testing and Monitoring Work Group provided guidance on the available methods to provide on-site data. Based on the T&M information, the aldehydes, BTEX compounds, n-Hexane, and 1-3, butadiene can be measured with test methods that will provide on-site data. There is no test method for naphthalene and PAHs that will provide on-site data. Therefore, the Work Group recommends that naphthalene and PAH data be collected through laboratory analysis, using CARB 429.

There is no EPA-approved method to measure PM emissions from stationary RICE. The EPA Method 5 is not appropriate for use on RICE due to the small diameter of the RICE stack (less than 0.3 meters) and the variability of the exhaust gases. The only EPA-approved method to measure PM from RICE is ISO Method 8178, which was developed to measure PM from RICE that are non-road, mobile engines.

The RICE Work Group recommends that FTIR be used to collect data on aldehydes, NOx, and CO. The Work Group recommends that the direct-interface GCMS method be used to collect BTEX, n-Hexane, and 1-3, butadiene data. The Work Group recommends that metals for diesel fuel be evaluated through fuel testing. The Work Group recommends that ISO Method 8178 be used to measure PM from the diesel engine to be tested. The Work Group recommends that the testing be conducted to achieve the lowest practical detection limits for all compounds. Preliminary information regarding achievable detection limits is provided in **Table 4**.

The proposed test methods for each proposed emission test are provided in the summaries of proposed emissions tests in the final section of this test plan. More information on sample collection is provided in **Appendix C**.

Table 4. Achievable Detection Limits for Test Methods Identified in RICE Test Plan

Test Method	Sample Time	Pollutants	Achievable Detection Limits
Direct Interface GCMS	10 minutes	BTEX 1,3-Butadiene Hexane	50 ppb 75 ppb 75 ppb
FTIR	10 minutes	BTEX 1,3-Butadiene Hexane Formaldehyde Acetaldehyde Acrolein NOx CO CH4	> 3 ppm > 3 ppm > 10 ppm 100 ppb 100 ppb 100 ppb 2-10 ppm 2-10 ppm 2-10 ppm
CARB 429	1 hour*	PAH Naphthalene	see note* see note*
EPA Method 25A	Continuous**	THC CH4	1-5 ppm 1-5 ppm
ISO 8178	2-10 minutes	PM	see note***

* Grab sample with 2-4 week analysis time. Detection limits dependant on sample time. A longer sample time will yield lower detection limits.

** Samples are run directly to a Flame Ionization Detector (FID) and measurements are made instantaneously.

*** ISO 8178 requires collection of at least 0.5 milligrams particulate matter.

6.0 PRIORITIZATION

The RICE Work Group has designed this Test Plan to give priority to emissions testing for the four engines identified. The Work Group recommends that emissions testing be conducted as described in this Test Plan.

7.0 SUMMARY OF PROPOSED EMISSIONS TESTS

7.1 Test #1: Clark TLA

Engine Subcategory:	**2-stroke, lean-burn, gaseous fuel**					
Engine to be Tested:	**Clark TLA Turbocharged**					
Fuel:	**Natural Gas**					
Control Device:	**Oxidation Catalyst**					
Pollutants to be Measured:	**Criteria Pollutants:** **NOx, CO, THC** **Hazardous Air Pollutants:** **Benzene, Toluene, Ethylbenzene, and Xylene(s)** **Formaldehyde, Acetaldehyde, Acrolein** **1-3, Butadiene, Naphthalene, PAHs**					
Test Methods to be Used:	**Direct-Interface GCMS Method for:** **Benzene, Toluene, Ethylbenzene, and Xylene(s)** **1-3, Butadiene** **FTIR for:** **Formaldehyde, Acetaldehyde, Acrolein** **NOx, CO** **Method 429 for:** **Naphthalene, PAHs** **Method 25A for:** **THC and CH4**					
Operating Conditions to be Tested:	**Speed**	**Torque**	**Air-to-Fuel Ratio**	**Timing**	**Air Manifold Temp.**	**Jacket Water Temp.**
Run 1	**H**	**H**	**N**	**S**	**S**	**S**
Run 2	**H[1]**	**L[1]**	**N[1]**	**S[1]**	**S[1]**	**S[1]**
Run 3	**L[2]**	**L[2]**	**N[2]**	**S[2]**	**S[2]**	**S[2]**
Run 4	**L[1,2]**	**H[1,2]**	**N[1,2]**	**S[1,2]**	**S[1,2]**	**S[1,2]**
Run 5	**H**	**H**	**L**	**S**	**S**	**S**
Run 6	**H**	**H**	**H**	**S**	**S**	**S**
Run 7	**H[2]**	**L[2]**	**H[2]**	**S[2]**	**S[2]**	**S[2]**
Run 8	**L[2]**	**H[2]**	**L[2]**	**S[2]**	**S[2]**	**S[2]**
Run 9	**H**	**H**	**N**	**S**	**L**	**S**
Run 10	**H**	**H**	**N**	**S**	**H**	**S**
Run 11	**H**	**H**	**N**	**S**	**S**	**L**
Run 12	**H**	**H**	**N**	**S**	**S**	**H**
Run 13	**H**	**H**	**N**	**L**	**S**	**S**
Run 14	**H**	**H**	**N**	**H**	**S**	**S**
Run 15	**H[3]**	**H[3]**	**N[3]**	**S[3]**	**S[3]**	**S[3]**
Run 16	**H[3]**	**H[3]**	**N[3]**	**S[3]**	**S[3]**	**S[3]**
	L[4]= 270 **H[4]= 300**	**L[4,5] = 70** **H[4,5] = 100**	**N[6] = 0.25** **L[6] = 0.22** **H[6] = 0.28**	**S = 4.5** **L = 2** **H = 7**	**S[7] = 100** **L[7] = 80** **H[7] = 120**	**S[8] = 150** **L[8] = 140** **H[8] = 160**

1) Runs #2 and #4 are not applicable if the engine at the test site is running a pump or blower, since the torque absorbed by a pump or blower is generally determined by speed.
2) Runs #3, #4, #7, and #8 are not applicable if the engine at the test site is running a synchronous generator, since synchronous generators do not vary speed.
3) Same as Run #1 except with engine at limit of acceptable imbalance.
4) Depending on site and operating conditions, speed and torque range may vary.
5) If unit has ambient rating controls capability, high torque value may be up to 124%.
6) Fuel/air equivalence ratio for this two-stroke cycle engine is based on total airflow through engine, not trapped air.
7) JWT setpoint is based on normal operating practices, but may vary depending on site-specific conditions.
8) IT setpoint is based on pipeline quality natural gas. IT is a function of engine speed and AMT.

7.2 Test #2: Caterpillar 3500 Series

Engine Subcategory:	**Liquid Fuel**					
Engine to be Tested:	**Caterpillar 3500 Series Turbocharged**					
Fuel:	**Diesel Fuel**					
Control Device:	**Oxidation Catalyst**					
Pollutants to be Measured:	**Criteria Pollutants:** **NOx, CO, THC, and PM** **Hazardous Air Pollutants:** **Benzene, Toluene, Ethylbenzene, Xylene(s)** **Formaldehyde, Acetaldehyde, Acrolein** **n-Hexane, 1-3, Butadiene, Naphthalene, PAHs** **Metals: Beryllium, Cadmium, Chromium, Lead, Manganese, Mercury, Nickel, Selenium**					
Test Methods to be Used:	**Direct-Interface GCMS Method for:** **Benzene, Toluene, Ethylbenzene, Xylene(s), n-Hexane, 1-3, Butadiene** **FTIR for:** **Formaldehyde, Acetaldehyde, Acrolein, NOx, and CO** **Method 429 for Naphthalene, PAHs** **Method 25A for THC** **ISO 8178 for Particulate Matter** **Fuel Testing for Metals**					
Operating Conditions to be Tested:	**Speed**	**Torque**	**Air-to- Fuel Ratio**	**Timing**	**Air Manifold Temp.**	**Jacket Water Temp.**
Run 1	**H**	**H**	**N**	**S**	**S**	**S**
Run 2	**H**[1]	**L**[1]	**N**[1]	**S**[1]	**S**[1]	**S**[1]
Run 3	**L**[2]	**L**[2]	**N**[2]	**S**[2]	**S**[2]	**S**[2]
Run 4	**L**[1,2]	**H**[1,2]	**N**[1,2]	**S**[1,2]	**S**[1,2]	**S**[1,2]
Run 5	**Not Applicable**					
Run 6	**Not Applicable**					
Run 7	**Not Applicable**					
Run 8	**Not Applicable**					
Run 9	**H**	**H**	**N**	**S**	**L**	**S**
Run 10	**H**	**H**	**N**	**S**	**H**	**S**
Run 11	**H**	**H**	**N**	**S**	**S**	**L**
Run 12	**H**	**H**	**N**	**S**	**S**	**H**
Run 13	**Not Applicable**					
Run 14	**Not Applicable**					
Run 15	**H**[3]	**H**[3]	**N**[3]	**S**[3]	**S**[3]	**S**[3]
Run 16	**H**[3]	**H**[3]	**N**[3]	**S**[3]	**S**[3]	**S**[3]
	L[4,5] **= 1000** **H**[4,5] **= 1200**	**L**[5] **= 70** **H**[5] **= 100**	**N = 0.68 (7.5% O2)** **L = 0.63 (8.5% O2)** **H = 0.74 (6.5% O2)**	**S = 28** **L = 26** **H = 30**	**S**[6] **= 130** **L**[6] **= 120** **H**[6] **= 140**	**S**[7] **= 160** **L**[7] **= 155** **H**[7] **= 165**

1) Runs 2 and 4 are not applicable if the engine at the test site is running a pump or blower, since the torque absorbed by a pump or blower is generally determined by speed.
2) Runs 3, 4, 7, and 8 are not applicable if the engine at the test site is running a synchronous generator, since synchronous generators do not vary speed.
3) Same as Run #1 except with engine at limit of acceptable imbalance.
4) Depending on rating of separable compressor unit, speed values may vary between 700 – 1200 rpm.
5) Depending on site and operating conditions, speed and torque range may vary.
6) AMT totally depends on type of cooler configuration.
7) JWT setpoint is based on normal operating practices, but may vary depending on site-specific conditions.
8) IT setpoint is based on diesel fuel.

7.3 Test #3: Waukesha 7042 GL

Engine Subcategory:	**4-stroke, lean-burn, gaseous fuel**					
Engine to be Tested:	**Waukesha 7042 GL Turbocharged**					
Fuel:	**Natural Gas**					
Control Device:	**Oxidation Catalyst**					
Pollutants to be Measured:	**Criteria Pollutants:** **NOx, CO, THC** **Hazardous Air Pollutants:** **Benzene, Toluene, Ethylbenzene, Xylene(s)** **Formaldehyde, Acetaldehyde, Acrolein** **1-3, Butadiene, Naphthalene, PAHs**					
Test Methods to be Used:	**Direct-Interface GCMS Method for:** **Benzene, Toluene, Ethylbenzene, Xylene(s)** **1-3, Butadiene** **FTIR for:** **Formaldehyde, Acetaldehyde, Acrolein, NOx, CO** **Method 429 for Naphthalene, PAHs** **Method 25A for THC and CH4**					
Operating Conditions to be Tested:	**Speed**	**Torque**	**Air-to- Fuel Ratio**	**Timing**	**Air Manifold Temp.**	**Jacket Water Temp.**
Run 1	**H**	**H**	**N**	**S**	**S**	**S**
Run 2	**H[1]**	**L[1]**	**N[1]**	**S[1]**	**S[1]**	**S[1]**
Run 3	**L[2]**	**L[2]**	**N[2]**	**S[2]**	**S[2]**	**S[2]**
Run 4	**L[1,2]**	**H[1,2]**	**N[1,2]**	**S[1,2]**	**S[1,2]**	**S[1,2]**
Run 5	**H**	**H**	**L**	**S**	**S**	**S**
Run 6	**H**	**H**	**H**	**S**	**S**	**S**
Run 7	**H[2]**	**L[2]**	**H[2]**	**S[2]**	**S[2]**	**S[2]**
Run 8	**L[2]**	**H[2]**	**L[2]**	**S[2]**	**S[2]**	**S[2]**
Run 9	**H**	**H**	**N**	**S**	**L**	**S**
Run 10	**H**	**H**	**N**	**S**	**H**	**S**
Run 11	**H**	**H**	**N**	**S**	**S**	**L**
Run 12	**H**	**H**	**N**	**S**	**S**	**H**
Run 13	**H**	**H**	**N**	**L**	**S**	**S**
Run 14	**H**	**H**	**N**	**H**	**S**	**S**
Run 15	**H[3]**	**H[3]**	**N[3]**	**S[3]**	**S[3]**	**S[3]**
Run 16	**H[3]**	**H[3]**	**N[3]**	**S[3]**	**S[3]**	**S[3]**
	L[4,5] = 1000 **H[4,5] = 1200**	**L[4] = 70** **H[4] = 100**	**N = 0.57** **(9.8% O2)** **L = 0.53** **(10.7% O2)** **H = 0.62** **(8.7% O2)**	**S[8] = 10** **L[8] = 6** **H[8] = 14**	**S[5] = 130** **L[5] = 120** **H[5] = 140**	**S[7] = 180**

1) Runs 2 and 4 are not applicable if the engine at the test site is running a pump or blower, since the torque absorbed by a pump or blower is generally determined by speed.
2) Runs 3, 4, 7, and 8 are not applicable if the engine at the test site is running a synchronous generator, since synchronous generators do not vary speed.
3) Same as Run 1 except with engine at limit of acceptable imbalance.
4) Depending on rating of separable compressor unit, speed values may vary between 700 – 1200 rpm.
5) Depending on site conditions, speed and torque range may vary.
6) AMT setpoint depends on type of cooler configuration.
7) JWT setpoint is fixed control per thermostat. May not be changed by user-defined control setpoint.
8) IT setpoint is based on pipeline quality natural gas.

7.4 Test #4: Ingersoll Rand KVG

Engine Subcategory:	**4-stroke, rich-burn, gaseous fuel**					
Engine to be Tested:	**Ingersoll Rand KVG Naturally Aspirated**					
Fuel:	**Natural Gas**					
Control Device:	**Non-Selective Catalytic Reduction (NSCR) 3-Way Catalyst**					
Pollutants to be Measured:	**Criteria Pollutants:** **NOx, CO, THC** **Hazardous Air Pollutants:** **Benzene, Toluene, Ethylbenzene, Xylene(s)** **Formaldehyde, Acetaldehyde, Acrolein** **1-3, Butadiene, Naphthalene, PAHs**					
Test Methods to be Used:	**Direct-Interface GCMS Method for:** **Benzene, Toluene, Ethylbenzene, Xylene(s)** **1-3, Butadiene** **FTIR for:** **Formaldehyde, Acetaldehyde, Acrolein, NOx, CO** **Method 429 for:** **Naphthalene, PAHs** **Method 25A for THC and CH4**					
Operating Conditions to be Tested:	**Speed**	**Torque**	**Air-to-Fuel Ratio**	**Timing**	**Air Manifold Temp.**	**Jacket Water Temp.**
Run 1	H	H	N	S	S	S
Run 2	H[1]	L[1]	N[1]	S[1]	S[1]	S[1]
Run 3	L[2]	L[2]	N[2]	S[2]	S[2]	S[2]
Run 4	L[1,2]	H[1,2]	N[1,2]	S[1,2]	S[1,2]	S[1,2]
Run 5	H	H	L	S	S	S
Run 6	H	H	H	S	S	S
Run 7	H[2]	L[2]	H[2]	S[2]	S[2]	S[2]
Run 8	L[2]	H[2]	L[2]	S[2]	S[2]	S[2]
Run 9	H	H	N	S	L	S
Run 10	H	H	N	S	H	S
Run 11	H	H	N	S	S	L
Run 12	H	H	N	S	S	H
Run 13	H	H	N	L	S	S
Run 14	H	H	N	H	S	S
Run 15	H[3]	H[3]	N[3]	S[3]	S[3]	S[3]
Run 16	H[3]	H[3]	N[3]	S[3]	S[3]	S[3]
	L[4] = 270 H[4] = 300	L[4] = 70 H[4] = 100	S = 1.00 L = 0.95 H = 1.05	S[7] = 15 L[7] = 12 H[7] = 18	See Note[5]	S[6] = 155 L[6] = 145 H[6] = 165

1) Runs 2 and 4 are not applicable if the engine at the test site is running a pump or blower, since the torque absorbed by a pump or blower is generally determined by speed.
2) Runs 3, 4, 7, and 8 are not applicable if the engine at the test site is running a synchronous generator, since synchronous generators do not vary speed.
3) Same as Run 1 except with engine at limit of acceptable imbalance.
4) Depending on site and operating conditions, speed and torque range may vary.
5) AMT totally dependent on ambient temperatures. 20 degree swing in temperature desirable for testing.
6) JWT setpoint is based on normal operating practices, but may vary depending on site-specific conditions.
7) IT setpoint is based on pipeline quality natural gas and may vary with certain ambient and operating parameters.